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Status and Trends of Wetlands in the Long Island Sound Area: 130 Year Assessment

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Inside cover photo: Barn Island Wildlife Management Area, Stonington, CT. Charlotte Murtishaw(USFWS).

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Abstract

This report provides the first 130 year assessment of tidal wetland change for the entire Long Island Sound Area. The results indicate an overall 31% loss of tidal wetlands with a 27% loss in Connecticut and 48% loss in New York. Despite tidal wetland legislation passed in 1970, wetland decline in Long Island Sound continues. After 1970 New York sustained a greater rate of wetland loss than Connecticut (-19% and 8% respectively). Current research points to multiple, nuanced and complex causes of present-day tidal wetland decline. A major present day concern is wetland vulnerability to loss due to potentially increased amounts of open water on the marsh surface. In this report we present the results of an open water assessment initially conducted in Connecticut. The literature suggests on average, healthy unditched New England marshes have 9% permanent open water on their surface. Our study indicates an average of 47% permanent open water on the marshes studied.

Understanding the extent and context of tidal wetland change is important for effective future protection. In addition to overall loss, we discuss the historic extent, present-day stressors and importance and implications of wetland decline to the Long Island Sound ecosystem. We summarize other local studies of marsh decline and degradation in portions of the Long Island Sound and conclude with recommendations for protecting this valuable habitat type given historic context and current stressors.

Introduction

Value of Tidal Wetlands

Tidal wetlands are among the most valuable of the earth's habitats from an ecosystem service perspective (Gedan 2009, Costanza 1997). They provide spawning, nursery and feeding grounds to resident and migratory marine organisms including shellfish, finfish and waterfowl; they play an important role in nutrient cycling within estuaries (Teal 1986, Mitsch 1993, Dahl 2013) and they provide services to people including storm protection, water purification, erosion control, nutrient sequestration and nursery habitat for fish (Weber 2014, Tiner 2013, Gedan 2009, Barbier 2011).

Saltmarshes play a particularly important role in nitrogen removal. Wetland vegetation slows water current and removes sediment and other pollutants including excess nitrogen. The nitrogen is deposited in the sediment or taken up by the plants. This improves water quality, stabilizes shorelines and prevents erosion and flooding (Teal 1986, Mitsch 1993).

Salt marshes also play a critical role in carbon sequestration. More than half of the global carbon load is captured by marine ecosystems and coastal vegetation. This carbon is known collectively as "blue carbon." The top three blue carbon sinks are mangroves, seagrass and saltmarshes (Nellemann 2009). These habitats not only remove more carbon than all other ocean habitat types but they remove it at rates up to 100 times faster than terrestrial forests (Nellemann 2009, "What is Blue Carbon?" 2014). Salt marshes have the highest average carbon burial rate per hectare per year of all the blue carbon sinks (Nellemann 2009) and although they cover a relatively small area, carbon burial by salt marshes accounts for an estimated 21% of the total carbon sink of all ecosystems in the United States (Bridgham 2006).

Salt marshes are a high-value habitat from multiple perspectives. Kocian (2015) estimated the economic value of the Long Island Sound area using benefits transfer methodology. Kocian concludes that coastal wetlands provide the highest monetary value of all the land cover types assessed in the Long Island Sound area, with an estimated range of $11,699 to $77,260 per acre per year (present-day values). This calculated value includes food, storm protection, wastewater treatment, habitat, nursery, recreation and tourism benefits.

Despite major restoration efforts and the immense value wetlands provide, marsh degradation due to human activity is extensive and increasing (Barbier 2011, Palmer 2008). To date, humans have damaged or destroyed about 50% of wetlands globally (Barbier 2011). Current threats include hydrologic modification, pollution, climate change, invasive species, herbivory and sediment deprivation (Silliman 2009, Kirwin 2013). Although significant, these threats do not doom wetlands to a trajectory of continued degradation. Humans can begin to change this trajectory and in fact have begun to do so successfully in some areas. Tampa Bay and San Francisco Bay as well as other estuaries across the country provide examples of communities coming together to make meaningful changes that allow for tidal wetland recovery.

The Importance of a Historic Perspective

Salt marshes are both extremely vulnerable and valuable to humans (Gedan 2009). Their continued decline has an impact on people and ecosystems (Nellemann 2009, Lotze 2006, Craft 2009). An understanding of historic reference points as well as extent of and reasons for degradation are critical to the success of large-scale restoration efforts (Lotze 2006). Historic information is valuable for goal setting **(**Shumchenia 2015, Rosenberg 2005**)**, helps prevent shifting ecological baselines **(**Rosenberg 2005) and allows for comparison across estuaries (Cicchetti and Greening 2011). Historic information provides perspective on the magnitude and impact of wetland loss (Lotze 2006) and can be applied to galvanize public support and spur further investigation into effective means of habitat protection (Cicchetti and Greening 2011).

Work conducted under the Tampa Bay National Estuary Program and the San Francisco Bay Area Wetlands Ecosystem Goals Project provide strong examples of how a historic perspective can be used to set goals, provide context, galvanize public support and advance meaningful restoration. In the case of Tampa Bay, managers used a historic context to frame initial habitat management discussions among partners. A common vision for ecological health arose out of these conversations. This vision was turned into quantifiable goals for a more ecologically desirable state of habitats in Tampa Bay (Cicchetti and Greening 2011). Understanding extent and consequences of loss can give higher weight to protecting what remains. This approach has been used in Tampa Bay to champion a collective goal to “hold the line” in terms of extent and function while moving toward a more ecologically desired state (Cicchetti and Greening 2011).

In the case of San Francisco Bay, managers and scientists calculated historic extent lost (Goals Project 1999) and used this historical context to estimate habitat acreage necessary to restore the ecological integrity of estuarine wetlands in the region. They used the scientific recommendations stemming from this large, collaborative effort to reset assumptions about the scale of restoration needed, galvanize political support for increased funding and remove barriers to progress that stemmed from disagreements about trade-offs among habitat types. Spurred by the Goals Project vision, estuarine wetlands restoration leapt forward on a much larger scale, even in this highly urbanized estuary (Goals Project 2015, in press).

In addition to providing a sense of the magnitude of loss, historic information can also help frame future change in a long-term context. This method can broaden managers' perspectives, encouraging a shift away from narrow goals (i.e. restore 200 acres) which in isolation can seem large, to a more holistic, ecosystem context (Rosenberg 2005).

While it may not be possible or even advisable to return to a historic condition (Duarte 2009), it is within our reach to regain and protect the suite of values wetlands provide to people and the environment (Lotze 2006). With the understanding of a broad historic context, Lotze (2006) encourages "regeneration" and restoration of the function provided by a network of coastal habitats so that they are able to absorb future disasters and shocks. Palmer (2009) suggests moving a degraded system toward a more ecologically desired state relative to a less disturbed time. By drawing on examples from other National Estuary Programs, applying the historic findings in this report and the results from studies on current stressors we can begin to identify and move toward a more desired state within the Long Island Sound Area.

Methods

This assessment was conducted on wetlands within the Long Island Sound Area coastal boundary (Figure 1). Long Island Sound is an estuarine water body of approximately 1,300 square located between the Connecticut shoreline and the north shore of Long Island, New York. The Long Island Sound is one of 28 National Estuaries designated by the U.S. Environmental Protection Agency (EPA) across the country. The red boundary (Figure 1) delineates the terrestrial and aquatic habitats that are within the Long Island Sound Area as per the National Estuary designation.

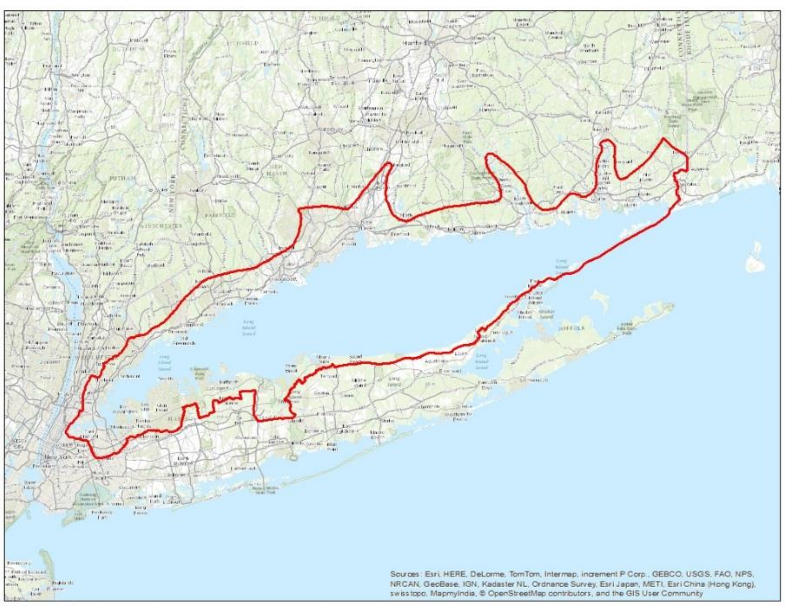


Figure 1. Red outline of the Long Island Sound Study coastal boundary

Wetland data was compiled from the late 19^{th} century, the early 1970s and early 2000s from the best available sources. These are summarized in Table 1 and described in greater detail in the appendix.

Table 1. Data sources for historic, intermediate, and present day estimates of wetlands

Year(s)	CT Data Sources	NY Data Sources
1880s	NOAA Topographic Survey Sheets (T-Sheets), 1880 – 1890s	NOAA Topographic Survey Sheets (T-Sheets), 1880 – 1890s
1970s	Connecticut Department of Energy and Environmental Protection (DEEP) 1970s Tidal Wetlands	New York State Department of Environmental Conservation 1974 Tidal Wetlands Map
2000s	National Wetlands Inventory (NWI) 2010-2012	National Wetlands Inventory (NWI) 2004-2009

A critical first step in these studies was to systematically understand and, where needed, standardize how wetland data were presented. By doing so, acreage estimates could then be calculated from each of these years to get a reasonable comparison of the amount of total acres gained or lost.

Using multiple data sources presented challenges to ensure that values calculated and analyzed represented true change as consistently as possible. Simply using acreages totals from the various data sets (Table 2) could under or over represent change if the data does not exist within the same or similar geographic extents or if the data included or omitted certain features. Further, assessing a rough magnitude of error is desirable to frame the results within a reasonable range of values rather than simply providing one calculation (See Appendix). In some cases, data collection and challenges were similar for both states. In other cases, due to differences in historic data and methodology, data was dealt with on a state by state basis in order to make it as comparable as possible between states.

Table 2. Total acreage values for original source data (unaltered)

	1880s	1970s	2000s
LISS	25,493	20,779	20,560
Connecticut	20,075	16,765	17,206
New York	5,418	4,014	3,354

Establishing a Common Area of Interest:

Overlaying the spatial data immediately identified a primary problem in conflicting extents. Figure 2 presents some examples. The wetlands collected from the T-sheets were constrained to the extent of the mapping strategy and the available maps. Confidence is high that all available maps from the given time period were collected and processed; however, the intent of the mapping itself was not to universally capture all areas of Connecticut and New York or even all areas of coastal Connecticut and New York. Rather, the intent of the T-sheets was primarily driven by capturing the shoreline and the general vicinity thereof as seen in Figure 3. So while there is much benefit to using this data, it cannot be construed to account for all areas of wetlands during the late 19th century.

Therefore, the extent of the 1970s and 2000 era data in both Connecticut and New York was spatially reduced by deleting or editing the boundaries of wetlands to create a similar spatial extent to that provided from the historic data. In some cases, minor alterations to the 1880s data were also performed to ensure conformity. While this exercise provided a unified area of interest, it resulted in the following noteworthy changes:

CT:

- Exclusion of wetlands from offshore islands from 1880s and 2000s
- Exclusion of wetlands in parts of several major river basins (Housatonic, Connecticut, & Thames) from 1970s and 2000s
- Exclusion of certain wetlands north of major transportation corridors in central CT from 1970s and 2000s
- Exclusion of small “fringe” patches of tidal wetlands from 2000s that exist off-shore or on the water-ward side of the shoreline.

NY:

- Exclusion of wetland complexes on Fisher’s Island, Mattituck Creek, and the Nissequogue River from 1970s and 2000s

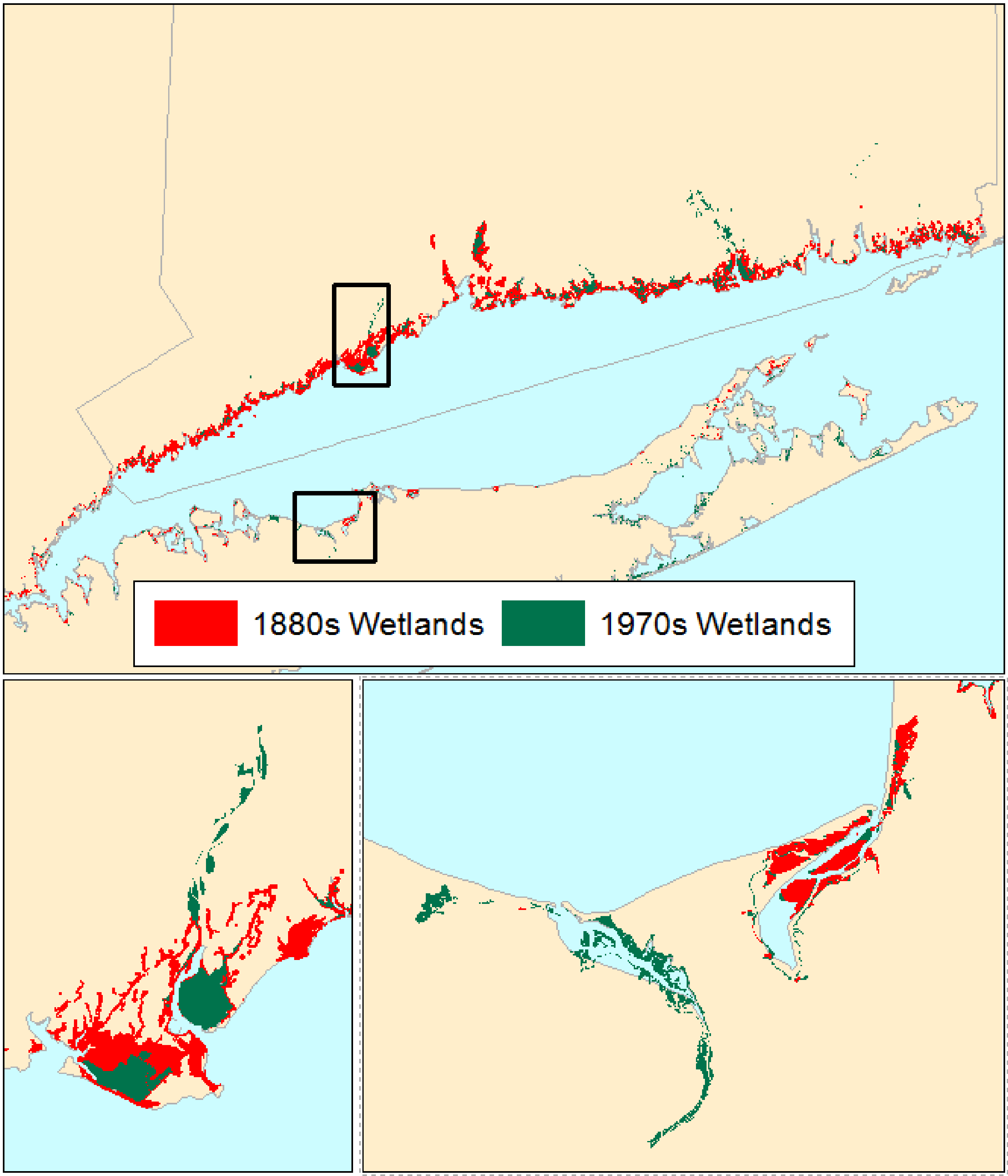


Figure 2. The 1880 and 1970 CT wetland data (top) differed in areas like the Housatonic River in Connecticut (lower left) and the Nissequogue River / Stony Brook Harbor area in New York (lower right.) Note the 1880 extents do not reach or cover the same areas as the 1970s

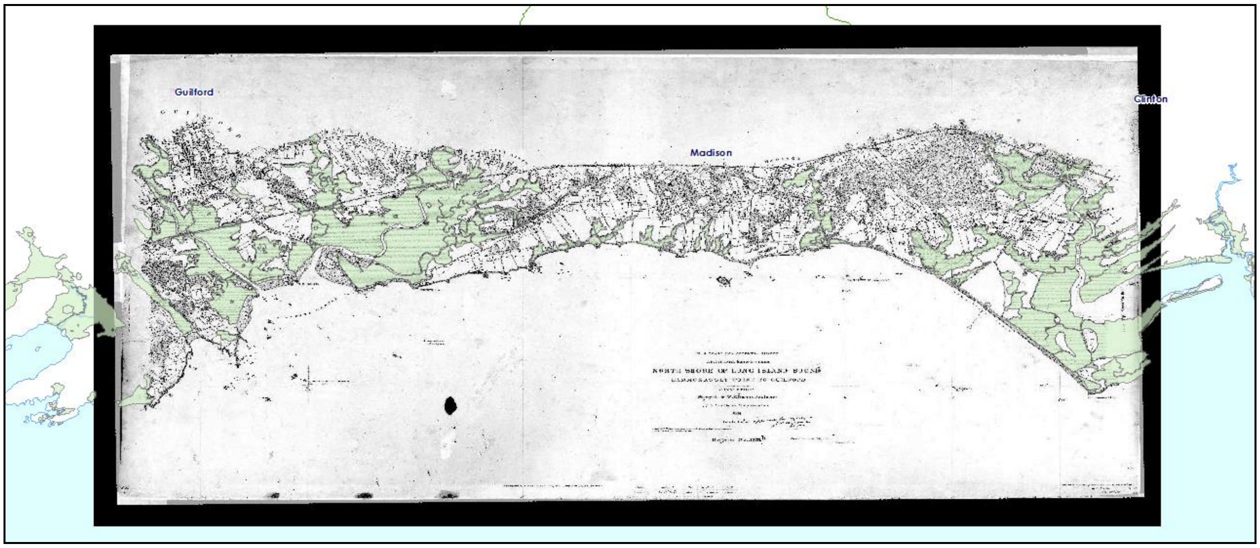


Figure 3. A sample T-Sheet image from Connecticut with wetlands delineated in green. Note the limit of the data captured is generally constrained to the shoreline.

Assessing Wetland Components:

In Connecticut, the 1970s data is known to have excluded wetlands on offshore islands, and that certain areas were omitted or missed. Further, wetland areas were not classified beyond labeling areas as 'wetland.' That is, there was no demarcation between any areas of internal landform features such as low marsh, high marsh, or hydrographic features (e.g., rivers, streams, or ditches, etc.) In Figure 4 the purple boundary defines the extent of a 1970 Connecticut wetland polygon on top of recent aerial photography showing landform and hydrographic features that were included in the calculation of marsh area.

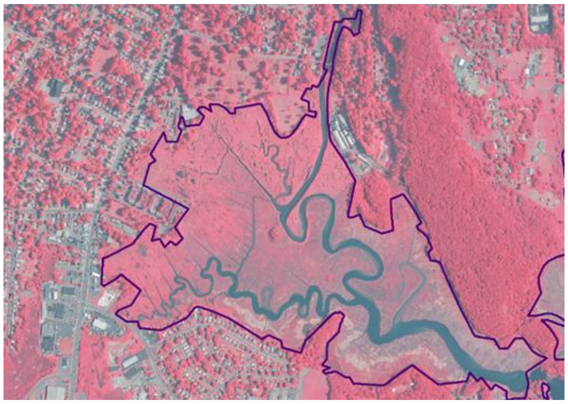


Figure 4. An example of 1970s wetland data for CT. Note the inclusion of hydrographic features as part of the polygon.

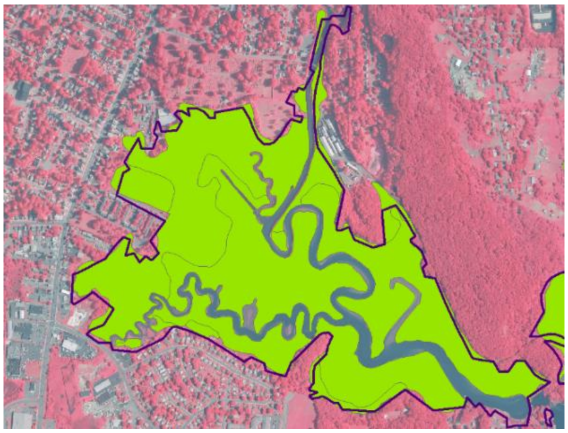


Figure 5. 2010 NWI Emergent Tidal Wetlands (green) and 1970s Wetland boundary (purple) in CT.

The 2010 NWI data for Connecticut provides information to extract the extent and classification of emergent, forested, and scrub-shrub tidal wetland areas in both brackish and freshwater regimes. When compared to the 1970s data, however, simply looking at these acreage values would suggest less area in 2010, as the hydrographic features are included in marsh area in the 1970s and excluded from marsh area in 2010. Figures 4 & 5 illustrate the same area presented by both data. To some degree this issue also affects the 1880s wetlands data for Connecticut; while it is technically feasible to fill in these gaps, the time and level of effort available are insufficient to do so for this assessment. Fortunately, NWI also includes areas of unconsolidated bottom that are generally analogous to the internal hydrographic features noted above. This allows a feasible way to provide a comparable estimate of change by including both areas of wetland proper as well as unconsolidated bottom in the 2010 NWI data. The unconsolidated bottoms were extracted from the 2010 NWI data using the 1970 boundary and were combined with the NWI wetland areas to best approximate the same relative extents of wetland areas for comparison (Figure 6). Note that only unconsolidated bottoms were clipped from the 2010 NWI data – the upland extents of emergent wetlands remain as-is. New York data did not have this issue and no adjustment for hydrographic feature was necessary.

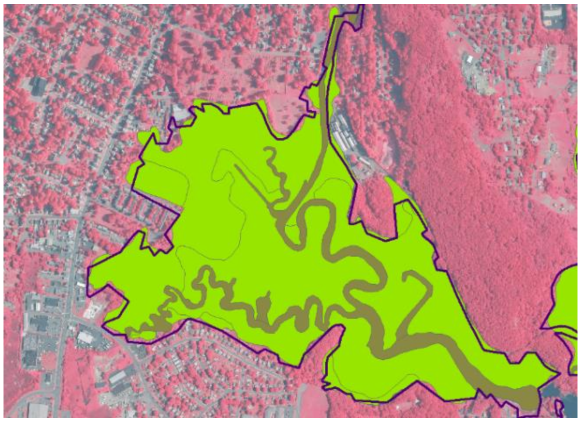


Figure 6. 2010 NWI Emergent Tidal Wetlands (green), Unconsolidated Bottoms (brown), and 1970s Wetland Boundary (purple) in CT.

The New York 2000s NWI data did indicate some areas where known wetlands were not included in the correct categories. Review of the data sets by resource managers from the New York Department of Environmental Conservation found that small, patchy, fringing wetlands were sometimes lumped in with Unconsolidated Shore category. These wetlands were too small to be mapped in their own right, but they were still visible from aerial photos. In the case of Oyster Bay Harbor, NY there were approximately 30 acres of Unconsolidated Shoreline that also contained small amounts of wetlands. Oyster Bay Harbor was the only complex in New York that seemed to show any certain quantifiable acreage mislabeled in this way. As a result, the approximate 30 acres found in Oyster Bay Harbor were not included in the analysis.

In contrast to the 1970 Connecticut data, the 1974 New York wetlands data provide a series of wetland categories. The intertidal marsh (IM), high marsh (HM), and fresh marsh (FM) categories were included as vegetated marsh for this assessment. The total acreage from these categories, plus the acreage from the formerly connected (FC) and dredge spoils (DS) make up the total New York 1974 acreage. The categories FC and DS pose a possible source of error because it is not possible to determine whether these two categories were actually vegetated wetlands or not. The 2000 vegetated tidal wetland acreage included the categories from the NWI with a class equal to "Estuarine and Marine Wetland," a category that most closely resembled vegetated wetland categories mapped in 1974.

A summary of how wetlands from 1970 and 2000 era data sets were synthesized in this study is illustrated in Table 3.

Table 3. Prominent wetland components included and excluded from 1970s and 2000s era data

NY- 1970s		CT- 1970s	
Included in acreage estimate	**Excluded**	**Included in acreage estimate**	**Excluded**
FC (Formerly Connected)	SM (Coastal Shoals and Mud Flats)	"Wetland" (includes areas of stream/river channels and ditches)	The dataset systemically excluded wetlands on offshore (were not surveyed) and intermittently excluded various wetlands.

DS (Dredge Spoils)	Unconsolidated bottom		
IM (Intertidal Marsh)	LZ (Littoral Zone)		
HM (High Marsh)	AA(Adjacent Area)		
FM (Fresh Marsh)			
NY- 2000s		**CT- 2000s**	
Included in acreage estimate	**Excluded**	**Included in acreage estimate**	**Excluded**
Estuarine Emergent (which encompassed IM, HM, FM, DS, FC)	Unconsolidated bottom	Estuarine Emergent brackish and tidal wetlands (see table X for full listing of NWI codes")	NWI features not encompassing brackish or freshwater tidal wetlands (e.g. freshwater non-tidal wetlands, unconsolidated shores, flats, etc.
	Unconsolidated shore (which is very similar to SM coastal shoals & mudflats in 1974)	Unconsolidated bottom (AB-US-UB-SB = aquatic bed, unconsolidated shore, bottom, stream) (Table 1)	NWI data on offshore islands and waterward of the shoreline.
	AA & LZ don't show up in 2010 NWI data		

As a result of the establishment of a common area of interest and adjusting wetland components, the revised acreage values for CT, NY and the LISS area that were analyzed are provided in Table 4.

Table 4. Revised tidal wetland acreages spatially reduced to the common footprint

Location	1880s	1970s	2000s
LISS	25,170	16,907	17,356
CT	19,828	13,443	14,566
NY	5,342	3,464	2,790

Open Water Assessment

In addition to an acreage change assessment we conducted a habitat quality assessment with respect to permanent open water (not tidal or rainfall) on the tidal marshes in Connecticut. Open water is considered an important indicator as wetlands are getting wetter, resulting in a loss of vegetated marsh in Connecticut (Tiner 2013). Using 2010 Tide Controlled Coastal Infrared Aerial Photography (Figure 7) coupled with field surveys we randomly sample 25% of tidal wetland units greater than 10 acres in each of the three Long Island Sound Study basins. We conducted photo interpretation of open water surface area with a team of wetland experts and followed up with field checks to verify surface conditions. The team visited 16 out of the 37 marshes included in the study and took an average of 23 point readings per marsh.

Cut points for extent of open water on the marsh were set based on input from wetland experts (Table 5). These cut points were also informed by recommendations developed for New England marshes (Adamowicz 2005). The "very good" indicator aligns with Adamowicz (2005) finding that the average amount of open water in an unditched New England marsh is 9% or 913 m^2/ha.

Table 5. Tidal wetland open water assessment: Indicators, metrics and cut points

Habitat	Indicator	Metric	Cut Points			
			Poor	Fair	Good	Very Good
Tidal wetlands	% open water low tide	Total pool surface area per hec (M2 of pool/ha saltmarsh)	> 20%	16 -- 20%	10 -- 15%	0 -- 9%

Results – Wetland Change

Table 6 presents a synthesis of the results. Of note, between the 1880s and 2000s there was an estimated 31% loss in tidal wetland acreage (approximately 7,841 acres) across the Long Island Sound Study area. The majority of this loss occurred before 1970 with a 35% loss in NY and a 32% loss in CT.

Between 1970 and today loss in CT slowed significantly. The data shows a small wetland gain (8%) which could be attributed to restoration acres, differences in how NWI classified land cover types, the way the 1970 data was developed (see appendix for brief description of the compilation methodology) or some combination of all three. Wetland loss in NY continued over that same time period with a 19% loss in acreage between 1970 and 2000s.

In summary, both states lost a substantial percentage of wetland acres between the 1880s and today, with NY losing an estimated 48% of wetland acres and CT losing 27% of its wetland acres. The subsequent section on error estimates provides a conservative ranges of values to frame upper and lower bounds among the geographies and timeframes.

Table 6. Estimated percentage change in wetland acres in the Long Island Sound Area

	1880s-1970s		1970s-2000s		1880s-2000s	
	Change (Acres)	Change (%)	Change (Acres)	Change (%)	Change (Acres)	Change (%)
LISS	-8,263	-33%	449	3%	-7,814	-31%
CT	-6,385	-32%	1,123	8%	-5,262	-27%
NY	-1,878	-35%	-674	-19%	-2,552	-48%

Results – Open Water Assessment

Marshes in the sample study had an average of 46% permanent open water at low tide (total pool surface area/ hectare of saltmarsh). Open water within each of the basins was above 20% (Table 7), putting all basins well within the poor range (Table 5). It should be noted that in 2010 the metonic cycle was high. This may contribute to more open water on the marsh surface during this time period.

Table 7. Open water scores by basin and overall habitat quality score

	Basin	TW acres	Open water acres	%OW
% open water at low tide	**Western**	345	113	33%
	Central	1394	684	49%
	Eastern	2821	1628	58%

Wetland Change Error Estimates – Providing upper and lower boundary estimates

Given the diversity of time and sources of data included in this analysis, it is appropriate to quantify some of the uncertainties and possible sources of error to provide a meaningful way to frame change. Shoreline change analyses that use data of similar vein and vintage can provide a reasonable way address this issue. Uncertainties for shorelines include errors introduced by data sources as well as errors introduced by measurement methods and are well documented (Anders 1991, Crowell 1991, Thieler 1994, Moore 2000, Ruggiero 2003). Here, we assume that the errors associated from delineating and mapping shorelines is more or less analogous to those applicable to creating wetland maps, and the methodologies used to define error bounds in (Taylor 1997) and (Hapke 2010) are equally valid. A more detailed presentation on the adaption and implementation of the methods can be found in Appendix; the results, however, provide the following:

- For Connecticut:
  - Data from the 1880s to the 1970s indicated that the computed change could conservatively vary between -40% and -18%.
  - Data from the 1970s to the 2000s indicated that the computed change could conservatively vary between +6% to +11%.
  - Data from the 1880s to the 2000s indicated that the computed change could conservatively vary between -37% to -9%

- For New York:
  - Data from the 1880s to the 1970s indicated that the computed change could conservatively vary between -40% and -33%.
  - Data from the 1970s to the 2000s indicated that the computed change could conservatively vary between -31% to + 9%.
  - Data from the 1880s to the 2000s indicated that the computed change could conservatively vary between -54% to -35%.

- For the entire LISS study area:
  - Data from the 1880s to the 1970s indicated that the computed change could conservatively vary between -39% and -22%.
  - Data from the 1970s to the 2000s indicated that the computed change could conservatively vary between -3% to +11%.
  - Data from the 1880s to the 2000s indicated that the computed change could conservatively vary between -40% to -14%.

Discussion

Given their importance to humans and wildlife, historic and present day marsh loss is a concern. This assessment indicates that historically (between 1880s and 1970s) CT and NY experienced a similar rate of decline (32% and 35% respectively). Post 1970, loss in CT may have slowed or stopped (8% gain) while loss in NY continues (19% loss). Overall Long Island Sound experienced a 31% decline in wetland acres, with CT having lost 27% of its wetland acres and NY having lost 48% of its wetland acres to date (Table 6). Wetland loss reduces the system's overall resilience, compromises ecosystem services like flood protection and carbon sequestration and can have a negative impact on biological diversity (Wigand 2014, Field 2014). In addition to wetland acreage loss in the LIS Area, salt marshes randomly sampled in the open water assessment had high amounts of permanent open water on their surface (on average 46% total pool surface area/ hectare of saltmarsh). The amount of permanent open water on marshes at low tide is a growing concern both locally and globally (Rozsa 1995, USFWS 2011).

Causes of Marsh Loss- Historic and Present Day

Some of the more substantial causes of loss before 1970 included dredge and fill operations (Rozsa 1995, Tiner 2012). By in large, this form of wetland destruction stopped in both states with the passage of tidal wetland acts in the 1970s (DEEP 2014, Tiner 2006, Rozsa 1995, Kirwan 2013). However, despite the legislation and restrictions, anthropogenic stresses continue to impact wetlands, resulting in loss within the LIS area (Mushacke 1999, Mushacke 2007). Although there is debate about which stressors are the main drivers of wetland decline, and this may be dependent on location, major stressors generally include nutrients, invasive species, sediment deprivation, hydraulic modification, pollution and climate change (Smith 2009, Gedan 2009, Wigand 2014, Watson 2014, Silliman 2009, Kirwan 2013). All are the result of human activities (Silliman 2009) and can act synergistically to deteriorate wetlands (Silliman 2009, Lotze 2006).

In contrast to the dredge and fill days of the past, the main cause of marsh loss in developed countries today is unintentional conversion of wetlands to open water (Kirwan 2013). Reasons for this conversion are complex and may include a combination of stressors. Irrespective of the causes, a growing body of research highlights instances and places where marshes are wetter and vegetated areas are shifting from high marsh to low marsh or to mud flat both locally and globally (Warren and Niering 1993, Muschacke 2007, Tiner 2006, Field 2014, Rozsa 1995, Watson et al. 2014, Smith 2009, USFWS 2011). Current research indicates that marsh transgression may not be happening quickly or consistently enough to prevent loss of high marsh (Field 2014).

Tiner (2006) found that all study areas experienced a decline in low marsh from 1974 to 2004 and a gain in tidal flats. All areas, except Cos Cob Harbor, also experienced a loss in high marsh. This type of wetland loss may be indicative of a regime shift. As described by Folke (2004), a regime shift is characterized by a shift from one ecosystem to another, often resulting in considerably less service and benefit to humans. It can be a difficult process to reverse (Folke 2004). Rozsa (1995) noted that on CT's Western shore large areas of marsh in Norwalk and on the Five Mile River have drowned. Warren and Niering (1993) note areas of high marsh in Southern New England that have transitioned to *S. alterniflora*, a plant species characteristic of low marsh. Field (2014) notes that high elevation marsh species (*Juncus gerardii*) are disappearing and lower elevation species (*Spartinia alterniflora*) are increasing. Muschacke (2007) did not attribute wetland loss in New York to a single cause but suspected sea level rise to be the primary driver of losses observed between 1974 and 2006. He noted that that some complexes along Long Island Sound, like Crab Meadow, exhibited a vegetative regime shift, where high marsh had shifted to low marsh. Muschacke surmised this conversion was the result of higher tides and greater flooding inundation. In our initial assessment we found that on average the marshes studied had well over 20% open water (Table 7), which is more water than is conducive to a functioning, healthy New England saltmarsh (Adamowicz 2005). This water is permanent open water and not pannes, pools, tidal or rainfall (Figure 7). The amount of water on many salt marshes in Connecticut indicates that they may be close to if not past a tipping point or regime shift (S. Adamowicz, pers. comm.).

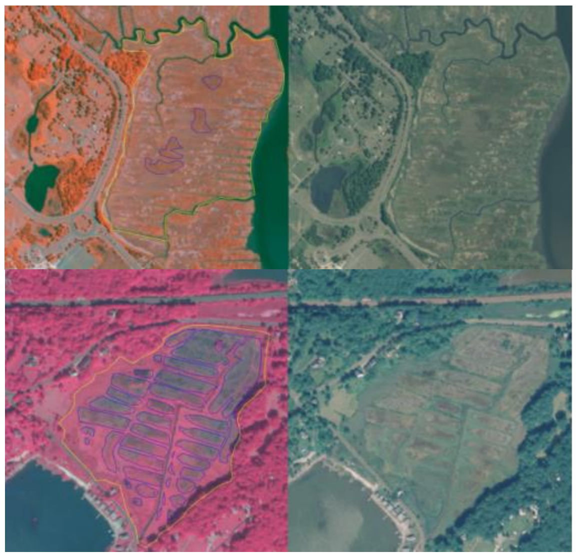


Figure 9. Infrared and true color photos of Very good (top, Hammonasset State Park, Madison) and Poor (bottom, Leetes Island, Guilford) and marshes surveyed along the CT Coast.

The work summarized above, specific to the LIS area also aligns with national trends. The most recent report from the USFWS on the status of our nation's wetlands concludes that 83% of wetland loss between 2004 and 2009 was due to salt water intrusion and conversion to open water (USFWS 2011). Wetter marshes pose a problem for the integrity of the marsh and the species that rely on them (Figure 8). In their 2014 study, Field et al found that Willet, Clapper Rail, Seaside Sparrow and Saltmarsh Sparrow populations in occupied salt marshes are declining on the Connecticut Coast. The amount of decline experienced by these four saltmarsh obligate saltmarsh species is consistent with what would be expected if sea level rise was the cause, with an inverse correlation between nest elevation and species decline whereby species nesting at the lowest elevation experience the steepest decline (C. Elphick, pers. comm.).

Figure 8. Saltmarsh sparrows nest exclusively in salt marshes, with high densities found in Connecticut's salt marshes. Nest density has declined over the past ten years, and the biggest cause of nest failure is flooding during especially high tides, which results in egg losses and nestlings drowning. Salt water intrusion likely threatens the future survival of the species. Photo credit: Jeanna Mielcarek (UCONN SHARP Lab)

The results of this assessment indicate that post-1970 losses are more substantial in New York than Connecticut. Accelerated loss in New York as compared to Connecticut may be due in part to differences in elevation and suspended solid loads between the two states.

Connecticut marshes appear to be higher in elevation than many marshes on Long Island (Figure 9, Watson et al. 2014). Watson looked at eight marshes in Rhode Island and New York and found that marshes at lower elevations experienced higher rates of vegetation loss (1970-2010) whereas higher elevation marshes had greater resilience. Marshes at a lower elevation are more vulnerable to conversion to mud flat than those at higher elevations due to sea level rise (Wigand 2014, Watson 2014). However, tidal range in Long Island Sound varies and marsh elevations approximate the height of mean high water (McKee and Patrick 1998). Coastal marsh vulnerability to sea level rise in Long Island Sound might more appropriately be measured as marsh height relative to the tidal datum of mean high water, rather than as marsh height relative to an orthometric datum (e.g., NAVD88). However, this metric is difficult to get as local tide stations have not been surveyed for orthometric heights and it is not possible to convert between water levels relative to a water level datum (e.g,. mean low water) and land elevations relative to an orthometric height (e.g., NAVD88). An additional confounding factor is that many coastal wetlands, in both New York and Connecticut are back barrier marshes where narrow tidal inlets traverse sand barriers. Such inlets restrict and modify tidal exchange, making it difficult to quantify tidal ranges or tidal heights without empirical data from water level loggers (E. Watson, pers. comm.).

A factor that may explain the perceived difference in elevation between Long Island and Connecticut's tidal marshes is availability of suspended sediments. Salt marsh vulnerability to sea level rise is a function of suspended sediment concentration and tidal range (Kirwan 2010). Limited sediment availability restricts a marshes ability to build upward in response to increased inundation. The Connecticut coast has substantial riverine inputs in comparison to Long Island (e.g, Bohlen 1975). For instance, the Connecticut River drains a watershed of 30,000 km^2 and delivers sediments to the coast unimpeded from the undammed portions of the watershed. In contrast, Long Island has few perennial rivers and creeks and natural sediment transport has in many cases been disrupted by urbanization. This contrast in sediment supply and transport pathways may help explain the rapid loss of wetlands in New York over past decades (E. Watson, pers. comm.). Sediment supply is however extremely site specific and is likely a concern for marshes in both states. As sea levels rise, the availability of suspended sediment is one of the main factors affecting wetland stability, particularly in the Northeast where sediment concentrations are naturally low and are declining (Weston 2014).

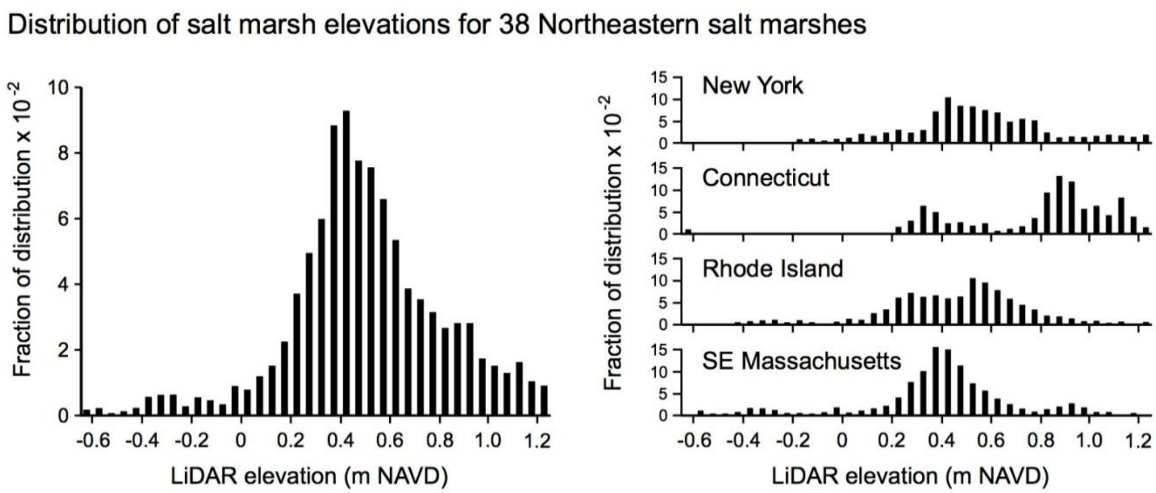


Figure 9. Marsh elevations are higher for Connecticut than other locations in the Long Island Sound and Southern New England region, where significant rates of marsh loss and conversion of high to low marsh are occurring (Hartig et al. 2002; et al. Smith 2009; Watson et al. 2014; Smith 2014). Figure reprinted from Watson et al. 2014.

Other Local Studies: A Summary

Although this assessment is the first of its kind to look at wetland acreage change over a 130 year period across the Long Island Sound Study Area as a whole, it is one of several studies to look at the concept of wetland change around the Sound in the more recent past (Rozsa 1995, Tiner 2006, Mushacke 2007, Tiner 2012, Cameron 2015).

Rozsa (1995) estimates that present day extent of wetlands for all of Long Island Sound is 20,895 acres, with CT's portion at 17,608 acres. Methodology behind these numbers was not included in the report. However, these estimates generally align with our estimates of total present day extent for the LIS Area at 20,560 (Table 2) with CT having 17,206 acres. Rozsa cites that historic estimates for CT around the turn of the century are between 22,265 - 26,500 acres. These historic estimates are also not accompanied by methodology therefore it is difficult to ascertain what wetlands were included in the calculations. This estimated range is slightly higher than our historic estimate of 20,075 acres in CT which we know to be limited by the upland cutoff of the T-sheets.

Rozsa (1995) cites a study CT DEEP conducted looking at tidal wetland differences between 1880 and 1970 for CT. This study estimated a 30% loss during that time, which is similar our 32% loss estimate for the same time period. Methodology was not included in the study so it is difficult to fully compare the results. Our results generally align with these earlier DEEP efforts. This present assessment helps reduce some of the previous uncertainty and lack of clarity regarding methodology by providing both extent estimates and detailed methodology behind them.

Tiner (2006) looked at change in overall acreage and marsh vegetation zones (low marsh and high marsh) in six salt marshes in southwestern Connecticut since 1974. Our 1970s-2000s results for CT generally align with the 2006 Tiner study which concludes that CT experienced a minimal loss of wetland acres from 1974 to 2004. Average acreage change in the salt marshes from 1974 to 2004 was 0.20% with no single marsh experience greater than 0.71% acreage loss. Although Tiner did not note a large shift in acreage, he did record a subtle, important change. All six areas in his study experienced a decline in low marsh and a gain in tidal flats from 1974 to 2004. All areas except one also experienced loss of high marsh. Tiner highlights sea-level rise as a likely major cause of shifts in marsh vegetation.

Tiner (2012) conducted a study of wetlands on Long Island from 1900-2004. The team built an estimate of 1928 wetland coverage using soil maps, soil data and 2004 wetland maps. Results show a significant loss in both North and South shore wetlands with an estimated 48% loss for all of Long Island's wetlands from 1928 to 2004. Tiner's study extends outside the LISS area. While it does not include a 1970s mid-point, the 2012 report aligns with our results in corroborating a general downward trend. Our results indicate this downward trend continued past 1970 and into the present time. The results of Tiner 2006 and 2012 corroborate our findings that wetland loss is more evident in New York than Connecticut.

Mushacke (2007) conducted a similar assessment of 8 salt marshes in the NY portion of the LISS. The study included a qualitative and quantitative (GIS) assessment. Mushacke (2007) compared aerial imagery from 1974, 1989 and 2005. The results indicate 11 - 79 % loss in marsh area from 1974 to 2002 for the sites assessed.

Cameron Engineering & Associates, LLP in association with Land Use Ecological Services, Inc. recently completed a tidal wetlands trends analysis for the entire NY portion of the Long Island Sound Study Area. This study uses infrared images to compare wetlands from 1974 to wetlands in 2005. Results indicate substantial loss of tidal wetland area over the past forty years. Total wetland area loss between 1974 and 2005 for the New York portion of the Long Island Sound Study is estimated to be 507.8 acres which is a -15.9% change. Our results are similar, indicating a -19% change from the 1970s to 2000s.

Tiner (2006), (2012) and Mushacke (2007) provide background and context to the results of this study and contribute to a growing body of research (Warren and Niering 1993, Rozsa 1995, USFWS 2011, Kirwin 2013) that points to reasons why, in the absence of dredge and fill operations, marsh acreage is still being lost.

In addition to local, site-based studies, it is important to look at change within the Long Island Sound in the context of regional and national trends. Every five years the USFWS releases a report on the state of the Nation's wetlands. The last report (2011) showed no statically significant change in tidal wetlands across the country from 2004-2009 (Figure 10). However, notable losses of tidal wetlands did occur in specific areas. The vast majority (83%) of these losses were due to saltwater inundation and conversation to open water. The report also identifies an increase in tidal mudflat area, originating primarily from conversion of previously vegetated marsh area.

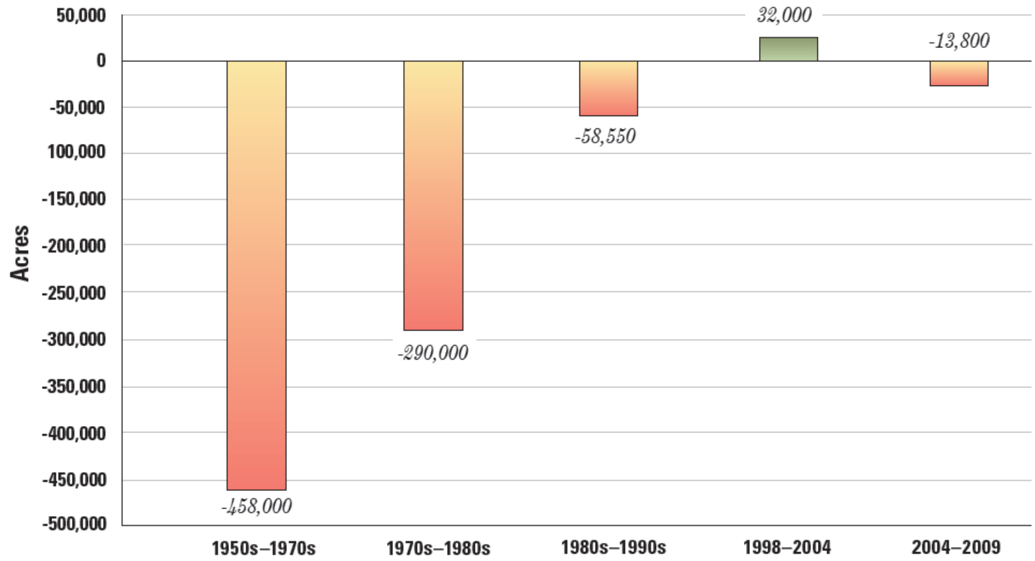


Figure 10 Average annual net losses and gain estimates for the conterminous US from 1954 to 2009. Source USFWS 2011

The USFWS national assessment supports locally observed and reported occurrences of marsh loss in the LIS Area. Local loss slowed significantly after the passage of legislation in the 1970s however decreases in vegetated marsh continue. Similar to the conclusions drawn in in the 2011 USFWS report for the nation, local loss may also be due to rising seas and conversion to open water.

Loss of Ecosystem Services

Loss and degradation of wetlands impacts ecological, social and economic parameters. A decrease in wetland area may lead to a loss of ecosystem services (Craft 2009). For example, the increase in flood damage, damage from droughts and decreased bird populations are all in part the result of wetland loss and degradation (EPA 2013). The Long Island Sound Area lost an estimated 7,814 acres of wetlands from 1880 to 2010 (Table 6). This loss estimate is restricted to the smallest common footprint (Table 4). If all of the historic acreage were mapped it is likely that the total acres loss would be greater than the loss estimate presented in this report. Therefore these ecosystem service loss figures are conservative estimates.

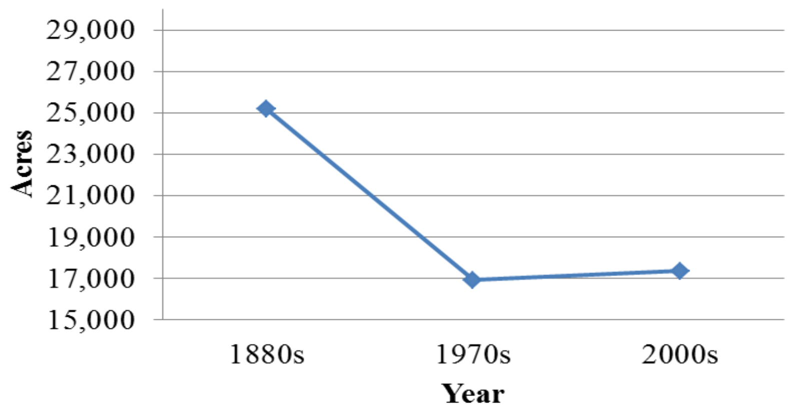
Using the dollar per acre value range for LIS saltmarshes, $11,699 to $77,260 acre per year (Kocian 2015) the present day economic impact of Long Island Sound's wetland loss is $91,415,986 - $603,709,640 per year (Figure 11).

Degrading wetlands release rather than retain carbon (Wigand 2014). Similar to the destruction of tropical rain forests, degradation and destruction of carbon sinks like wetlands can contribute to the acceleration of climate change (Nellemann 2009). Wetland loss has a large impact because among all of the terrestrial and marine carbon sinks wetlands sequester the most carbon (Nellemann 2009). Using the mean organic carbon burial rate for salt marshes, 3.73 Tons C per acre per year (Nellemann 2009) the present day carbon impact of wetland loss in the Long Island Sound area is the lost sequestration ability of an estimated 29,146 tons of carbon annually (Figure 11).

As wetlands decline, ecosystem services provided by their ability to retain and remove nitrogen are reduced (Craft 2009). Using the mean nitrogen sequestration rate, 2.39 Tons N per acre per year (Craft 2009), nitrogen sequestration in the soil is reduced by 18,675 tons per year (Figure 11).

Long Island Sound National Estuary

Tidal Wetland Extent



Loss of Ecosystem Services per yr
Economic loss of $91,415,986 - $603,709,640
Carbon sequestration reduced by 29,146 tons
Nitrogen sequestration reduced by 18,675 tons

Figure 11. Change in tidal wetland extent (1880s- 2000s) in the Long Island Sound National Estuary and estimated corresponding loss of value. Equivalency values from Nelleman2009, Craft 2009, Kocian 2015.

Recommendations for the Long Island Sound Area

Results of this assessment indicate a substantial loss of wetlands in the LIS area over the last 130 years. Loss rates have slowed, but have not stopped. As compared to the dredge and fill operations of the past, today wetlands are experiencing a more subtle form of degradation, associated with a changing climate, rising seas and altered sediment regimes. High amounts of open water on the marsh surface found in the assessment presented in this report highlight one potential present day stress on local marshes. Regional models predict a 20-45% loss in tidal wetland acreage over the current century (Craft 2009). Although current threats are significant, they are not intractable. It is possible to turn the table and create a more optimistic future for wetlands and ourselves (Rosenberg 2005). In an effort to change the loss trajectory for Long Island Sound's wetlands we suggest moving toward an ecosystem focus, working to address multiple threats and effectively engaging the public to bolster support for ecologically meaningful restoration. We provide brief detail on these three recommendations below:

1. Define and protect wetland condition and function on a Sound-wide basis

Restoration in the Long Island Sound Area has mainly taken an opportunistic, marsh by marsh approach. Site selection and treatment are primarily based on funding, willing partners and site-specific treatment selections. These are the realities of on-the-ground restoration. However, as evidenced by continued and in some areas rapid decline, this approach may not be enough to meet the complex, nuanced and increasing threats facing the Sound’s marshes.

We recommend defining goals to maintain an ecologically desired range for wetland condition and function in the Sound. Setting these goals and acting on them to restore *wetland function and value* will require thinking along broad temporal and spatial scales, taking historic information into account and moving past a marsh by marsh approach to restoration (Silliman 2009). An example goal could take the following form, "maintain a network of ecologically resilient wetlands that provide (an agreed-upon level) of services with no net wetland acreage loss beyond a 1970 baseline." This process should be informed by data provided in this report and through other recent studies and workshops (e.g. Field et al 2014, Tiner 2006, 2012, O'Neill 2015). Partners in the Long Island Sound Estuary are well positioned to lead this collaborative, ecosystem level approach to define and restore wetland function.

2. Address co-occurring and site-specific threats

Stressors on marshes vary across the globe (Silliman 2009) as well as locally within the Long Island Sound (Anisfeld 2015, in review). Our results show different rates of loss between the two States and high levels of open water on the marshes studied. Given stressors acting on marshes within the Sound and different loss rates between the two States, a tailored approach may be needed. We recommend that this approach take into account the often overlapping, synergistically nature of threats to wetlands (Lotze 2006, Duarte 2009, Silliman 2009, Rosenburg 2005). We have a growing body of research and predictive models on local stressors and marsh response to those stressors (TNC of marsh migration work, SLAMM, Tiner 2013, Anisfeld 2015 in review, Field 2014). Based on the results from this study we recommend advancing this information where necessary (i.e. better understanding causes of open water on the marsh, how threats act synergistically). However, we caution against seeking complete information before making a move. Given the suitable state of current information and continued wetland decline, we recommend the LIS community act now by developing a tailored plan that incorporates new approaches where appropriate, takes the effects of synergistic threats and local stressors into account and clearly outlines restoration actions in order to meet condition and function goals defined through Recommendation One.

3. Engage people

Results from this study and others indicate that loss of marsh translates into a loss of ecosystem services which has social and economic implications for people. Other programs show the galvanizing effect that an understanding of the extent of loss can have on spurring public support for large-scale restoration. These programs also show the powerful role people can play in defining ecological thresholds and setting goals around desired levels of habitat function. We recommend applying the results from this study and others to create a pervasive awareness of habitat health, an understanding of benefits natural habitats like wetlands provide for local communities and a sense of ownership within local communities in the restoration process. With this groundwork established, we recommend working within communities to identify common goals for wetland recovery including an ecologically acceptable range relative to less disturbed conditions (Palmer 2009, and see Recommendation One)

Changing the course of wetland loss in the Long Island Sound areas is an achievable goal. Success will depend on partners' ability to galvanize public support and act in a strategic and timely fashion.

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Appendix

Error Estimates:

Given the diversity of time and sources of data included in this analysis, it is advantageous to assess some of the uncertainties and possible sources of error to provide a meaningful way to frame change. Simply providing statements on acreage quantities without some reasonable window or range fails to acknowledge the nature of the data and can cloud or skew the results being presented. Shoreline change analyses that use data of similar vein and vintage can provide a reasonable way address this issue under the assumption that working with shorelines and wetland boundaries are largely comparable in their collection and interpretation.

Uncertainties for shorelines include errors introduced by data sources as well as errors introduced by measurement methods, and are well documented: (Anders & Byrnes, 1991) (Crowell, Leatherman, & Buckley, 1991) (Thieler & Danforth, 1994); (Moore, 2000) (Ruggiero, Kaminsky, & Gelfenbaum, 2003). The potential errors involved in deriving shoreline data make it necessary to provide a best estimate of the total positional uncertainty associated with each shoreline position. The following five components are considered when estimating the positional uncertainty for shorelines:

1) georeferencing uncertainty;
2) digitizing uncertainty;
3) T-sheet survey uncertainty;
4) air photo collection and rectification uncertainty; and
5) the uncertainty of the high water line at the time of survey (Crowell, Leatherman, & Buckley, 1991)

For this analysis, we explicitly assume the uncertainty in surveys and field determining shoreline boundaries are the same as the uncertainty when applied to wetland boundaries.

For each shoreline or wetland boundary, the position uncertainty is defined as the square root of the sum of squares (Taylor, 1997) of the relevant uncertainty terms, based on an assumption that each term is random and independent of the others (Hapke, Himmelstoss, Kratzmann, List, & Thieler, 2010). The average values for each uncertainty term and the total average positional uncertainty were estimated using methods described in (Hapke, Himmelstoss, Kratzmann, List, & Thieler, 2010) and are provided in Table <I>

Table <I>: Potential source material and values for error

Measurement Errors (meters)	*Tsheets*		*Air Photos*
	1880s-1950s	*1960s-1980s*	*1970-2000s*
Georeferencing	*4*	*4*	*0*
Digitizing	*1*	*1*	*1*
Tsheet survey	*10*	*3*	*0*
Air Photos	*0*	*0*	*3*
Shoreline location	*4.5*	*4.5*	*4.5*

Measurement Errors (meters)	*Tsheets*		*Air Photos*
Square root of Sum of Squares (meters)	***11.72***	***6.80***	***5.50***
Square root of Sum of Squares (feet)	***38.43***	***22.31***	***18.04***

For the 1880-1890 wetland data derived directly from the T-sheets, the same measurement error sources and values can be applied. Thus, we can conclude that there is a range of approximately +/- 38 feet for any wetland boundary taken from the 1880s T-sheets.

The 1970s era wetland data sources of error for CT & NY involve a slightly different suite of parameters based on the methods used to collect and create it, and the 2000s era NWI data did not specifically provide a measure of horizontal accuracy. However we know in general that the 1970s era wetlands data was generated from a combination of field surveys and aerial photo interpretation, and the 2000s era NWI data relied on aerial photo interpretation. Therefore, using the T-Sheet error values from Table <I>, we can extract the relevant terms and apply the same calculations. The results are shown in table <II>:

Table <II>: State and NWI measurement errors

Measurement Errors (meters)	*CT & NY 1970's era Tidal Wetlands Data*	*CT & NY 2000 era NWI Wetlands Data*
	1970-2000s	*1970-2000s*
Digitizing	*1*	*1*
Tsheet/Wetland survey	*3*	*0*
Air Photos	*3*	*3*
Shoreline/wetland boundary location	*4.5*	*4.5*
Square root of Sum of Squares (meters)	***6.26***	***5.50***
Square root of Sum of Squares (feet)	***20.53***	***18.04***

We conclude that there is a range of approximately +/- 21 feet for any wetland boundary coming from the 1970s era Tidal Wetlands data and a range of approximately +/-18 feet for any wetland boundary represented by 2000 era NWI data.

We used the ranges provided by the sum of squares analysis to generate estimates for high and low end acreage adjustments to the base acreage values from the data by a buffering geoprocessing function using GIS. To simply the process, buffers were only generated on the exterior edges of wetlands, and it was assumed that this over-estimate would provide a comparable under-estimate. Buffers for each wetland were automatically merged together to account for any overlap from adjacent wetlands and prevent over counting. Table <III> presents the results when summed across all wetland data within a given source/vintage.

Table <III>: Error adjustment values

Wetland Data Source (reduced to common footprint)	Estimated Amount of Boundary Error (feet)	Resulting acres of error adjustment
CT 1880s wetlands	+/- 38	+/- 5323
CT 1970s wetlands	+/- 21	+/- 1575
CT 2000s wetlands	+/- 18	+/- 1382
NY 1880s wetlands	+/- 38	+/- 1997
NY 1970s wetlands	+/- 21	+/- 1464
NY 2000s wetlands	+/- 18	+/- 612

Adding and subtracting the adjustment values from Table <III> with the wetlands area values from the GIS layers used in this study then yields the following value ranges from which we can calculate differences and percentage differences (Table <IV>).

Table IV: Summary results for long term and short term wetland change

Change Comparison (Time)	Wetland Data Sources (reduced to common footprint)	Adjusted Acres (boundaries reduced)	GIS acres (presented by the actual delineated boundaries)	Adjusted Acres (boundaries increased)
1880s to 1970s	CT 1880s wetlands	14,505	19,828	25,151
	CT 1970s wetlands	11,868	13,443	15,018
	Difference	*-2,637*	*-6,385*	*-10,133*
	Percent	*-18%*	*-32%*	*-40%*
1970s to 2000s	CT 1970s wetlands	11,868	13,443	15,018
	CT 2000s wetlands	13,184	14,566	15,948
	Difference	*1,136*	*1,123*	*930*
	Percent	*11%*	*8%*	*6%*
1880s to 2000s	CT 1880s wetlands	14,505	19,828	25,151
	CT 2000s wetlands	13,184	14,566	15,948
	Difference	*-1,321*	*-5,262*	*-9,203*
	Percent	*-9%*	*-27%*	*-37%*
1880s to 1970s	NY 1880s wetlands	3,421	5,342	7,415
	NY 1970s wetlands	2,000	3,464	4,928
	Difference	*-1,421*	*-1,878*	*-2,487*

Change Comparison (Time)	Wetland Data Sources (reduced to common footprint)	Adjusted Acres (boundaries reduced)	GIS acres (presented by the actual delineated boundaries)	Adjusted Acres (boundaries increased)
	Percent	*-42%*	*-35%*	*-34%*
1970s to 2000s	NY 1970s wetlands	2,000	3,464	4,928
	NY 2000s wetlands	2,179	2,790	3,402
	Difference	*179*	*-674*	*-1,526*
	Percent	*9%*	*-19%*	*-31%*
1880s to 2000s	NY 1880s wetlands	3,421	5,342	7,415
	NY 2000s wetlands	2,179	2,790	3,402
	Difference	*-1,242*	*-2,552*	*-4,013*
	Percent	*-36%*	*-48%*	*-54%*
1880s to 1970s	LISS study area 1880s	17,926	25,170	32,566
	LISS study area 1970s	13,868	16,907	19,946
	Difference	*-4,058*	*-8,263*	*-12,620*
	Percent	*-23%*	*-33%*	*-39%*
1970s to 2000s	LISS study area 1970s	13,868	16,907	19,946
	LISS study area 2000s	15,363	17,356	19,350
	Difference	*1,495*	*449*	*-596*
	Percent	*11%*	*3%*	*-3%*
1880s to 2000s	LISS study area 1880s	17,926	25,170	32,566
	LISS study area 2000s	15,363	17,356	19,350
	Difference	*-2,563*	*-7,814*	*-13,216*
	Percent	*-14%*	*-31%*	*-41%*

Data Source Descriptions

Historic Wetlands (1880s – 1890s:)

Wetland features for Connecticut and New York were digitized using National Oceanic and Atmospheric Administration (NOAA) Topographic Survey Sheets (T-sheets) spanning the late 19th century, roughly the late 1880s to late 1890s. T-Sheets were used to derive the 1880 estimate for both states using the same methodology. T-Sheets can be used for ecological research, specifically studying and illustrating landscape change. They offer tremendous value as one of the earliest records of coastal area land cover and they are exceptionally accurate and detailed for their time (Grossinger 2005). T-Sheets of the Long Island Sound Study area are among the most accurate in the country (Graham pers. comm.). That said, these historic records do have their limitations because they were produced for specific reasons, mainly the identification of shoreline boundaries to support shipping and navigation, which may leave out important landforms (Grossinger 2005).

In 2004, digital versions of paper maps were provided to DEEP by the National Geodetic Survey (NGS) and were georeferenced (properly oriented to align in a common frame of reference) by the University of Connecticut. All available T-Sheets for NY were downloaded directly from the NOAA Shoreline website in 2010 which also included supplementary data files to properly georeferenced them. In addition, a small number of maps covering the New Haven Harbor area in Connecticut that were not included in the original set from NGS were also downloaded.

Once the maps were properly oriented, features were manually digitized. The digitizing process included wetland areas and interior wetland water bodies as defined by map legends or inferred based on symbology and general location within the maps. These data do not include any non-wetland-centric elements that may have been depicted on the t-sheets such as buildings, roads, bridges, etc. Semi-submerged marshes (interpreted as "low marshes,") occurring where it is possible to discern marsh-like features waterward of the shoreline were captured; conversely, every effort was made to exclude other similar yet distinct features like mud flats, tidal flats, etc. It should be noted, however, that map image quality affecting boundaries and inconsistencies in symbology used by cartographers from map to map may have resulted in non-tidal wetland features being inadvertently captured.

Wetlands circa 1970s:

- CT: Tidal wetland data from the 1970's represents the historic regulatory tidal wetland boundaries produced during the early 1970's by the State of Connecticut Department of Agriculture and Natural Resources, which defined the areas of tidal wetlands that were subject to the 1969 Tidal Wetlands Act. These regulatory tidal wetland boundaries were surveyed in the field and then subsequently transferred to 1" = 200' (1: 24000 scale) mylars derived from black and white low altitude aerial photography. It is known that the mapping criteria changed and evolved as the surveyors became more experienced with tidal wetland delineation. It also was not unusual for controversial parcels to be omitted as a result of adverse comments received at public hearings prior to the adoption of the maps. Additionally, no maps were ever produced to show "formerly connected" wetlands, a special type of wetlands. Thus, even at the time of their adoption, the 1970's tidal wetland maps did not include all known tidal wetlands in Connecticut. However, they represent the most complete set of data available for that time period.

- NY: New York State Department of Environmental Conservation’s 1974 Tidal Wetlands data represent the regulated tidal wetlands in New York State. Mylar maps were made from 1974 color infrared aerial photography (1 inch = 1,000 feet, 1:12,000 scale). These aerials were enlarge and best-fitted to New York State DOT maps at a scale of 1 inch = 2,000 feet (1:24,000). These mylar maps were then digitized using ARC/INFO. The polygons were reprojected from NAD27 to NAD83 to match the 2010 NWI data. In order to correctly compare the area calculations from each dataset, they all must be in the same projection.

Modern Wetlands circa 2000s:

The National Wetlands Inventory (NWI) datasets for Connecticut and New York represent the extent, approximate location and type of wetlands and deepwater habitats of the conterminous United States and were developed by the US Fish & Wildlife Service. These data delineate the areal extent of wetlands and surface waters as defined by Cowardin et al. (1979). Certain wetland habitats are excluded from the National mapping program because of the limitations of aerial imagery as the primary data source used to detect wetlands. These habitats include seagrasses or submerged aquatic vegetation that are found in the intertidal and subtidal zones of estuaries and near shore coastal waters. By policy, the Service also excludes certain types of "farmed wetlands" as may be defined by the Food Security Act or that do not coincide with the Cowardin et al. definition.